CHAPTER 7
CONCRETE PAVEMENTS

7-1. Application.

In general, all concrete pavements for roads, streets, and open storage areas on military installations will be plain concrete unless otherwise approved by Headquarters, Department of the Army (CE MP-ET), Washington, DC 20314-1000, or the appropriate Air Force Major Command. Roller-compacted concrete pavements (RCCP) are plain concrete pavements constructed using a zero-slump PCC mixture that is placed with an asphalt concrete paving machine and compacted with vibratory and rubber-tired rollers. Most of the engineering and material properties of RCCP are similar to those of conventional concrete. Pavements constructed using RCCP have been approved for use in parking and storage areas and for road and street classes where vehicle speed does not exceed 45 miles per hour.

7-2. Design Procedure.

The design of a concrete pavement for mixed vehicular loads and traffic levels is based on Minor's hypothesis. It involves selecting a thickness of the PCC slab in which the maximum tensile stress does not exceed a certain value. This tensile stress is calculated using the JULEA computer program, and the limiting stress criteria are based on equations 5-1 and 5-2. Since traffic loads travel near the pavement (free) edges, load transfer is not considered in the design for roads and streets but is considered for parking and storage areas.

a. Select several concrete slab thicknesses and compute the maximum tensile stresses under each design axle load using the layered elastic method. The concrete thickness required using the conventional design procedure may be used as a starting point. The computed maximum stresses should be multiplied by 1.33 for roads and streets.

b. Based on the computed stresses, determine the allowable coverages N using equation 5-1 for each thickness.

c. Compute the damage which is equal to the sum of the ratios of the design coverage n_i to the allowable coverage N_i, where i varies to account for each design axle load. For instance, if there are three different axle loads involved in the design, I varies from 1 to 3.

d. Select the thickness at a damage of 1.

e. Select the slab thickness for the damage value of 1 from the relationship between the damage and slab thickness.

f. The selection of an unbound granular base or a stabilized base under the concrete slab is a matter of engineering judgment depending on many factors such as cost, material availability, frost protection requirement, pumping, and subgrade swell potential. Subgrade soil may be stabilized to gain strength or modified to increase its workability and reduce swell potential.

g. All plain concrete pavements will be uniform in cross-sectional thickness. The minimum thickness of concrete will be 6 inches. The computed thickness will be rounded to the next full or half-inch thickness.

7-3. Design Procedures for Stabilized Foundations.

a. Soil stabilization or modification. Soils that have been treated with additives such as cement, lime, flyash, or bitumen are considered to be either stabilized or modified. A stabilized soil is one that shows improvement in load-carrying capability and durability characteristics. A modified soil is one that shows improvement in its construction characteristics but which does not show an increase in the strength of the soil sufficient to qualify as a stabilized soil. The principal benefits of soil modification or stabilization include a stable all-weather construction platform, a reduction of concrete pavement thickness requirements, and when applicable, a reduction of swell potential and susceptibility to pumping and strength loss due to moisture.

b. Requirements. The design of the stabilized or modified layers will follow TM 5-822-4/AFM 88-7, Chap. 4, and TM 5-822-5/AFM 88-7, Chap. 3. To qualify as a stabilized layer; the stabilized material must meet the unconfined compressive strength and durability requirements in TM 5-822-14/AFJMAN 32-1019; otherwise, the layer is considered to be modified.

c. Thickness design. The thickness requirements for a plain concrete pavement on a modified soil foundation will be designed as if the layer is unbound using the k value measured on top of the modified soil layer. For stabilized soil layers, the treated layer will be considered to be a low-strength base pavement and the thickness determined using the following modified partially bonded overlay pavement design equation:

$$h_o = \sqrt[1.4]{h_d^{1.4} - \left(\sqrt[3]{\frac{E_f}{E_c}}\, h_s\right)^{1.4}} \qquad \text{(eq 7-1)}$$

where

h_o = thickness of plain concrete pavement overlay required over the stabilized layer; inches

h_d = design thickness of equivalent single slab placed directly on foundation determined from layered elastic method

E_c = modulus of elasticity of concrete, usually taken as 4 x 106 psi

E_f= flexural modulus of elasticity of the stabilized soil. The modulus value for bituminous stabilized soils will be determined according to the procedures in appendix B of TM 5-822-5/AFM 88-7, Chap. 3.
The modulus value for lime and cement stabilized soils will be determined using equations in appendix B of TM 5-822-5/AFM 88-7, Chap. 3

h_s = thickness of stabilized layer; inches

7-4. Reinforced Concrete Pavements.

Figure 7-1 is a design chart for determining the thickness of reinforced concrete pavement based on the thickness of the plain concrete pavement and the amount of steel to be used in the pavement. Figure 7-1 also shows the maximum allowable length of reinforced concrete slab.

7-5. Design Examples.

a. The input information needed for the design are as listed in paragraph 2-2. Based on the trial pavement sections, the critical stresses and strains are computed using the elastic layered computer codes. Damage from each vehicle group is summed and the design thickness is determined when the cumulative damage is equal to one.

b. In the computation, the following values are used.

(1) The interface between the concrete slab and the subgrade soil is assumed to be frictionless and the parameter equal to 10,000 is used in the computation.

(2) The moduli and Poisson's ratio of the PCC and the subgrade are 4,000,000 psi, 0.2, 10,000 psi, 0.4, respectively.

(3) The tire contact pressure is assumed to be 70 psi. In tracked vehicle, the track width is constant and the contact pressure varies with the gross load.

c. Example No.1. This example is to show the procedures for determining the elastic modulus values of unbound granular base and subbase courses from figure B-1.

(1) Assume a concrete pavement having a base course thickness of 4 inches and a subbase course thickness of 8 inches over a subgrade having a modulus of 10,000 psi. Initially, the subgrade is assumed to be layer n + 1 and the subbase course to be layer n. Entering figure B-I with a modulus of layer n + 1 of 10,000 psi and using the 8-inch subbase course curve, the modulus of the subbase (layer n) is found to be 18,500 psi. In order to determine the modulus value of the base course, the subbase course is now assumed to be layer (n + 1). Entering figure B-I with a modulus of layer n + 1 of 18,500 psi and using the 4-inch base course curve, the modulus of the base course is found to be 36,000 psi.

(2) If, in this example, the design thickness of the subbase course had been 12 inches, it would have been necessary to divide this layer into two 6-inch-thick sublayers. Then, using the procedure above, the modulus values determined for the lower and upper sublayers of the subbase course and for the base course are 17,500, 25,500, and 44,000 psi, respectively.

d. Example No. 2.

(1) As an example of the application of the design procedures given for nonstabilized foundations, determine thickness requirements for a plain concrete road to carry the following traffic:

Passenger cars	2,000 per lane per day
Panel and pickup trucks	1,300 per lane per day
Trucks, 2-axle	150 per lane per day
Trucks, 3-axle	50 per lane per day

For each type of vehicle, the operations per coverage ratios are obtained from table 5-1 and used to convert operations to coverages according to axle configurations. The computed coverages for each axle type are tabulated in table 7-1.

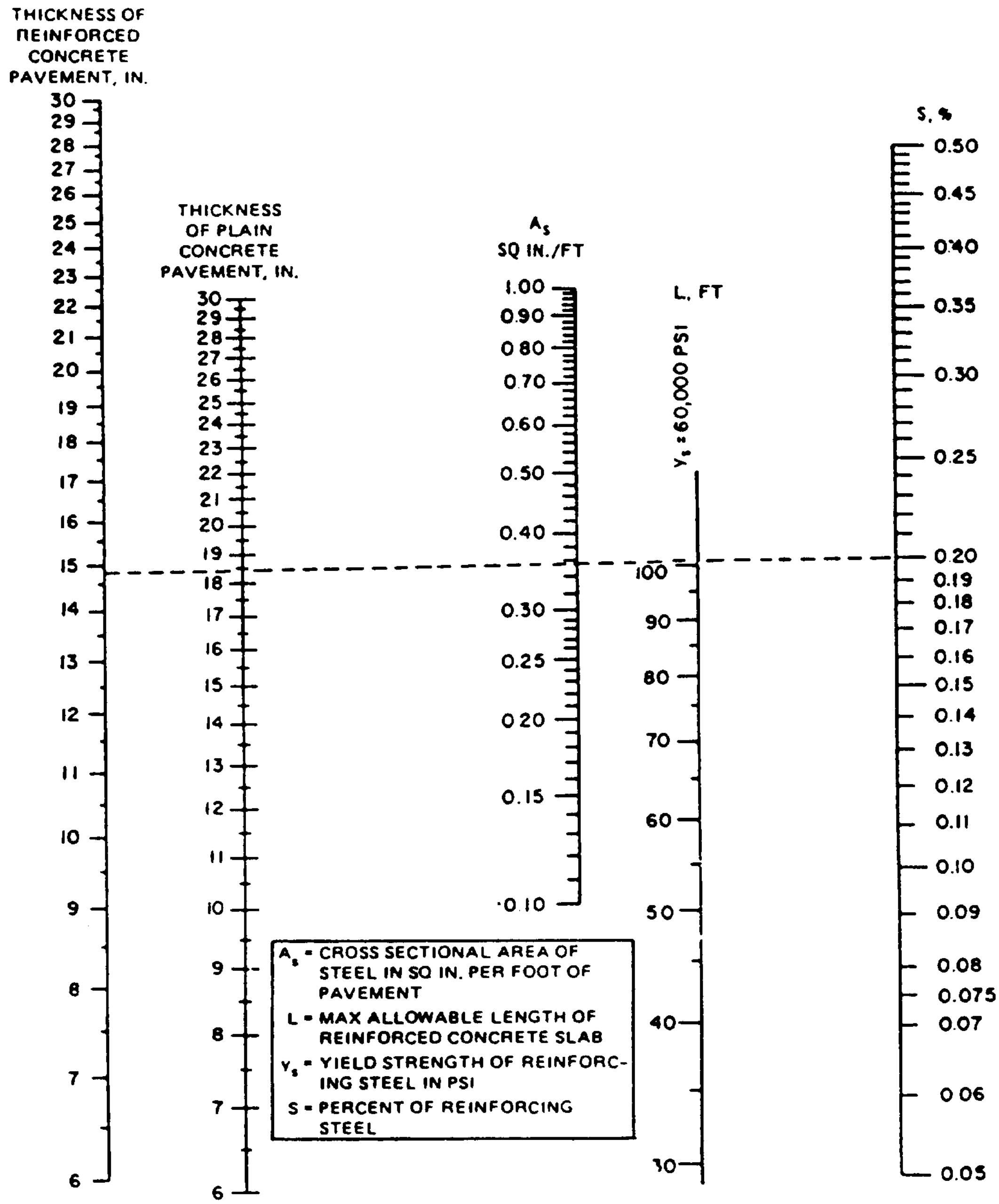

Figure 7-1. Reinforced Concrete Pavement Design.

(2) The required concrete thickness is first determined using the current design procedure presented in TM 5-822-5/AFM 88-7, Chap. 3 as a starting point. Assuming an E value of 10,000 psi for the subgrade soil, four concrete thicknesses were selected as shown in table 7-2, and the maximum stresses were computed using JULEA computer program for all the axle configurations. The stresses are tabulated in column 4 of table 7-2. Since load transfer is not considered in roads and streets for concrete pavements as wheel and track loads travel along the concrete slab edges, stresses computed with codes such as JULEA (interior stresses) do not simulate the edge stress condition and thus the computed stresses will be multiplied by a factor of 1.33. The modified stresses are shown in column 5 of the table. Assuming a 28-day flexural strength R for the concrete of 675 psi and a SCI of 80, the allowable coverages were computed using equation 5-1. The damage is computed as the ratio of design coverage n~ to the allowable coverage N~, and is presented in column 8 of the table; the cumulative damage for design thicknesses of 6, 7, 8, and 10 inches is 58.6, 3.8, 0.2, and 0.0, respectively. A plot of these values indicates a required concrete thickness of 7.2 inches for a damage factor of one. This thickness value would be rounded off to 7.5 inches for design.

Table 7-1. Computed Design Coverages for Example 2.

Vehicle Type	Configuration	Load* kips	Operations Per Lane, Per Day	Operations** Per Coverage	Coverage Per Lane, Per Day	Coverage† Per Lane, 25 years
Passenger cars	Single axle, single wheels	1.5	2 × 2,000	9.59	417.1	3,806,037
Panel and pick-up truck	Single axle, single wheels	3.0	2 × 1,300	9.59	271.1	2,473,787
Truck 2-axle	Single axle, single wheels	9.0	150	6.25	24.0	219,000
	Single axle, dual wheels	18.0	150	2.64	56.8	518,300
Truck 3-axle	Single axle, single wheels	9.0	50	6.25	8.0	73,000
	Tandem axle, dual wheels	32.0	50	2.06	24.3	221,737

*Some loads are assumed values.
**Values are obtained from Table 5-1.
†Values are obtained by multiplying 25 × 365 to the value of coverages per lane per day.

Table 7-2. Computations of Cumulative Damage for Example 2.

Axle Type (1)	Load kips (2)	Slab Thickness, in. (3)	Maximum Stress σ_{max} psi (4)	1.33* × σ_{max} psi (5)	Allowable** Coverage N_i (6)	Design Coverage n_i† (7)	Damage n_i/N_i (8)
Single-axle single wheels	1.5	6	35.6	47.35	Too large	3,806,037	0.0
	1.5	7	26.9	35.78	Too large	3,806,037	0.0
	1.5	8	21.2	28.20	Too large	3,806,037	0.0
	1.5	10	14.2	18.89	Too large	3,806,037	0.0
Single-axle single wheels	3.0	6	66.4	88.31	Too large	2,473,787	0.0
		7	51.5	68.50	Too large	2,473,787	0.0
		8	40.8	54.26	Too large	2,473,787	0.0
		10	27.7	36.84	Too large	2,473,787	0.0
Single-axle single wheels	9.0	6	169.0	224.77	2,845,700	21,900	0.01
		7	133.0	176.89	Too large	21,900	0.0
		8	108.0	143.64	Too large	21,900	0.0
		10	75.2	121.43	Too large	21,900	0.0
Single-axle dual wheels	18.0	6	251.0	333.83	8,839	518,300	58.6
		7	204.0	271.32	137,152	518,300	3.8
		8	170.0	226.10	2,564,720	518,300	0.2
		10	124.0	164.92	Too large	518,300	0.0
Tandem-axle dual wheels	32.0	6	205.0	272.65	127,698	221,737	1.7
		7	169.0	224.77	2,854,733	221,737	0.0
		8	144.0	191.52	Too large	221,737	0.0
		10	111.0	147.63	Too large	221,737	0.0

*1.33 is the factor to account for no-load transfer free edge stress conditions.
**Computed from equation 5-1.
†Values obtained from table 7-1.

e. Example No.3.

(1) To illustrate the design procedure for tracked vehicles, it is assumed that a concrete pavement is to be designed for an average of 10 Ml tanks per lane per day. The Ml tank has the following characteristics:

Gross weight	120 kips
track spacing (c to c)	112 inches
Truck width	25 inches
'track contact width	18.75 inches (=0.75 x 25)
track length	180 inches
Number of bogies per track	7.0
Operations per coverage ratio	0.33 (from table 5-1)

(2) To use computer codes such as the JULEA computer program, the track load will be converted into eight uniformly distributed circular loads. Each circle has a diameter of 17.25 inches (the width of the track) and a load of 7,500 pounds. The distance between bogies is 20.4 inches center to center. The computed maximum stresses for several concrete thicknesses are tabulated in column 2 of table 7-3. The maximum stress in this case occurs under the center load. In other cases, the location of the maximum stress needs to be determined. This is done by computing stresses in many locations and selecting the maximum stress. Following the procedures in example 2, a plot of concrete thickness (column 1) against damage (column 6) shows that the design concrete thickness is 13.7 inches. This thickness value would be rounded off to 14.0 inches for design.

Table 7-3. Cumulative Damage Computed for M1 Tank.

Slab Thickness in. (1)	Maximum Stress σ_{max} (2)	$1.33 \times \sigma_{max}$ (3)	Allowable* Coverage N_i (4)	Design** Coverage n_i (5)	Damage n_i/N_i (6)
8	347	461.5	329	273,204	830
10	275	365.8	3,124	273,204	87
12	224	297.9	37,137	273,204	7.4
14	185	246.1	615,013	273,204	0.4

*SCI = 80, R = 625 psi.

**Design coverages for 25 years is 25 x 365 x 10/0.33 = 273,204.

f. Example No.4. To illustrate the procedure for conventional traffic plus forklift trucks and tracked vehicles, design a concrete pavement road for the following traffic:

Passenger cars	300 per lane per day
Panel and pickup trucks	200 per lane per day
trucks, 2-axle	100 per lane per day
Trucks, 3-axle	40 per lane per day
Truck-laying vehicles, 120,000 pounds (Ml tank)	2 per lane per day
Forklift trucks, 25,000 pounds (Pneumatic tires)	20 per lane per day

Table 7-4 shows the design coverages for each wheel or track configuration, and table 7-5 shows the computed maximum stresses and damage. The cumulative damage for concrete thicknesses of 8, 10 and 12 inches is 34.2, 3.4 and 0.3, respectively. A plot of these values indicates a required concrete thickness of 11.2 inches for a damage of one. This thickness value would be rounded off to 11 inches for design.

7-6. Joints.

The design and construction of joints for plain and roller-compacted concrete, the design and installation of dowel bars, special provisions for slipform paving, and joint sealing are presented in TM 5-822-5/AFM 88-7, Chap. 3.

7-7. Design Details.

Typical details for the design and construction of plain concrete pavements are contained in TM 5-822-5/AFM 88-7, Chap. 3.

Table 7-5. Computations of Cumulative Damage for Example 4.

Axle Type	Load kips	Slab Thickness in.	Maximum Stress σ_{max} psi	$1.33 \times \sigma_{max}$ psi	Allowable* Coverage N_i	Design** Coverage n_i	Damage n_i/N_i
Single axle single wheels	1.5	8	21.2	28.2	Too large	574,875	0.0
	1.5	10	14.2	18.9	Too large	574,875	0.0
	1.5	12	10.2	13.6	Too large	574,875	0.0
Single axle single wheels	3.0	8	40.8	54.3	Too large	383,250	0.0
		10	27.7	36.8	Too large	383,250	0.0
		12	20.1	26.7	Too large	383,250	0.0
Single axle single wheels	9.0	8	108.0	143.6	Too large	200,750†	0.0
		8	75.2	100.0	Too large	200,750	0.0
		12	55.6	74.0	Too large	200,750	0.0
Single axle dual wheels	18.0	8	168.0	223.4	3,171,527	346,750	0.11
		10	124.0	164.9	Too large	346,750	0.0
		12	95.3	126.7	Too large	346,750	0.0
Tandem axle dual wheels	32.0	8	144.0	191.5	61,348,000	173,375	0.0
		10	111.0	147.6	Too large	173,375	0.0
		12	89.6	119.1	Too large	173,375	0.0
M1 Tank	30.0 per track	8	353.0	469.5	284	9,125	32.2
		10	279.0	371.1	2,678	9,125	3.4
		12	227.0	301.9	31,122	9,125	0.3
Forklift truck	25.0	8	230.0	305.9	26,202	52,010	2.0
		10	169.0	224.8	2,845,729	52,010	0.0
		12	130.0	172.9	571,536,300	52,010	0.0

*SCI = 80, R = 675 psi.
**Values obtained from table 7-4.
†It is the sum of 146,000 and 54,750 from table 7-4.